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CHANGES OF VASCULAR AQUATIC FLOWERING PLANTS DURING 70 YEARS IN PUT-IN-BAY HARBOR, LAKE ERIE, OHIO[1, 2]

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ABSTRACT

Based on a survey in 1898, 40 species of vascular aquatic flowering plants were reported for Put-in-Bay harbor in western Lake Erie. Studies of this flora at various times since then have revealed a loss of species from this harbor to the extent that today 20 species of the original 40, or 50%, of the flora has disappeared. Only three of the original 40 can be considered to be common or abundant today in the harbor. During the same 70-year period, only four submersed species have invaded the harbor. Possible reasons for these changes, such as increase in water temperature, decrease in oxygen, increase in turbidity, and man's influence on the harbor by dredging, building retaining walls, increasing use of motor boats, dumping of domestic sewage, and runoff from agricultural land are all considered as possible factors that have, independently and interrelatedly, in part or in total, been responsible for this 50% loss in species composition. Comparisons with data from studies of Lake East Okoboji, Iowa, and University Bay in Lake Mendota, Wisconsin, reveal that the changes in species composition of the aquatic flora in Put-in-Bay harbor are very similar to those changes that have occurred in Lake East Okoboji, and that a trend similar to that in Put-in-Bay harbor and Lake East Okoboji is developing in University Bay of Lake Mendota. Species characteristic of clear, cool, well-oxygenated waters, whose distributions are primarily northern and whose ecological tolerances are apparently narrow, have disappeared, whereas species of turbid, warm, poorly oxygenated waters, whose distributions are primarily widespread and whose ecological tolerances are apparently wide, have survived.

One of the most diverse communities of vascular aquatic flowering plants in the Great Lakes region, and perhaps even elsewhere in the United States, once flourished in Put-in-Bay harbor in western Lake Erie. Seventy years ago, 40 species of vascular aquatic flowering plants grew in this bay and adjoining waters. Today, however, only half of these still survive, and several of these species are rare and in danger of disappearing from this area. The habitats and the environment of Put-in-Bay harbor have changed largely because of man's use of the lake and bay, resulting in a 50% loss of these species in 70 years. This paper records and documents the changes that have occurred in this aquatic flora since about 1900.

SOURCES OF DATA

The record of the vascular aquatic flowering plants in western Lake Erie, and in particular for Put-in-Bay harbor, is unique in that it is one of the longest and most complete aquatic floristic records in North America (Tables 1 and 2). Even

[1]Contribution from the Department of Botany (Paper No. 772), the Herbarium, and the Franz Theodore Stone Laboratory, The Ohio State University, Columbus, Ohio 43210. Portions of this paper were presented to the Plant Sciences Section at the annual meetings of the Ohio Academy of Science at Ohio Wesleyan University, Delaware, 25 April 1969, and at the University of Akron, 23 April 1971, and to the Conference on Coastal Zone and Shoreline Management in the Great Lakes, Traverse City, Michigan, 27 May 1971.

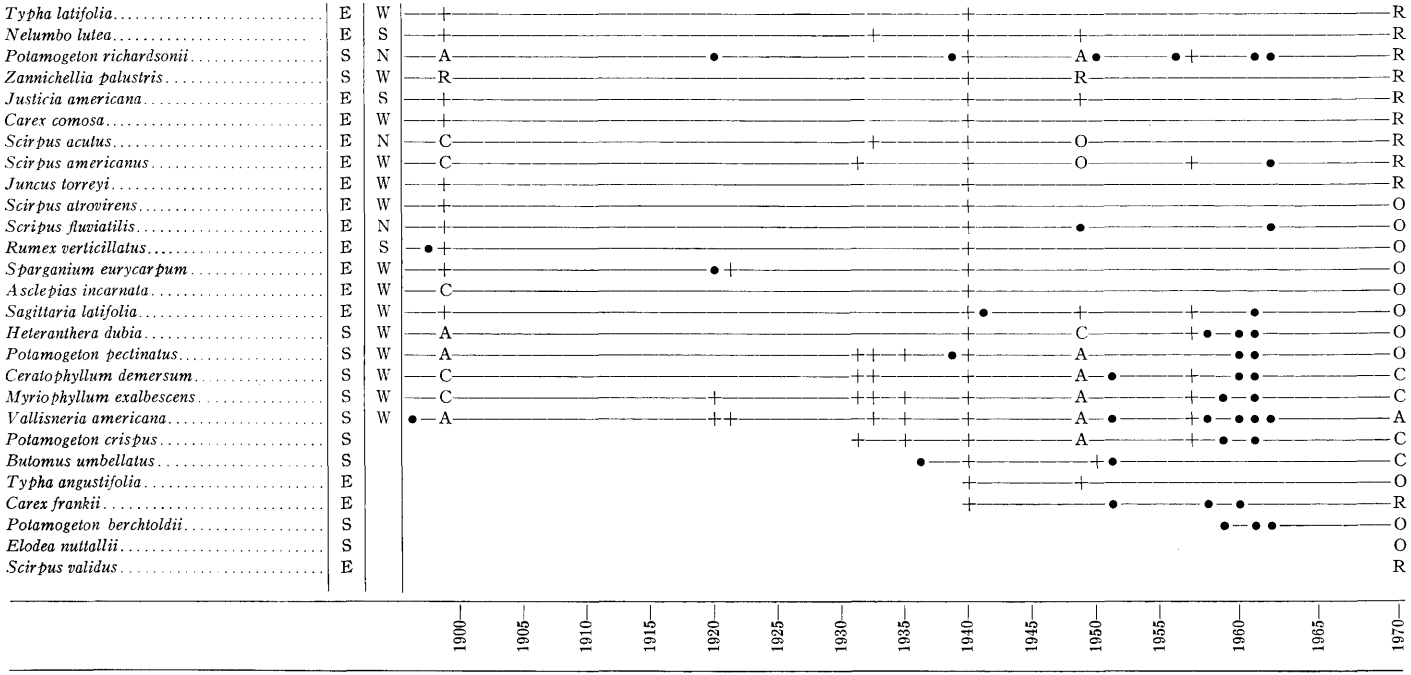
[2]Manuscript received July 7, 1971.

TABLE 1

Documented changes of vascular aquatic flowering plants during 70 years in Put-in-Bay harbor, Lake Erie, Ohio, compiled from the literature and herbarium records

Dates of Observations (Numbers in parentheses are publication dates.)[1]

	Growth Habit[2]	Geographical Distribution[3]	1898 Pieters (1901)	Stehle (1923); Kennedy (1923)	1924 Krecker (1924)	1931 Shawver (1931)	1933 Tiffany (1934, 1937)	Krecker (1939)	Core (1948)	1949 Core (1949)	1957 Stansbery (1961)	1967 Stuckey
Potamogeton amplifolius	S	N	+									
Potamogeton friesii	S	N	O									
Potamogeton praelongus	S	N	+									
Potamogeton perfoliatus	S	N	+									
Megalodonta beckii	S	N	+									
Najas guadalupensis	S	S	A									
Scirpus expansus	E	S	+									
Carex aquatilis	E	W	+									
Potamogeton filiformis	S	N	R						+			
Potamogeton gramineus	S	N	C						+			
Potamogeton natans	S	N	+						+			
Sagittaria rigida	E	N	C						+			
Potamogeton nodosus	S	S	+				+		+			
Nuphar advena	E	S	C		+	+			+			
Potamogeton pusillus	S	W	A						• +	A		
Potamogeton foliosus	S	W	+	•					+	+		
Nymphaea tuberosa	E	S	+			+			+	+		
Elodea canadensis	S	W	C	+		+	+	+	+	C	+	
Najas flexilis	S	N	A				+	+	+	A	+	
Potamogeton zosteriformis	S	N	A			+	+	+	• +	C	•	



1. Abundance values as given in or inferred from the literature for the data between 1890–1966, and as determined by Stuckey in the 1967–1970 study (see text):
   A=Abundant
   C=Common
   O=Occasional
   R=Rare
   +=Present (Used when abundance values are not known)
   ●=Herbarium specimen record (known herbarium specimens cited in Table 2 are available for most of the 1898 records of Pieters (1901), the 1939–1941 records of Core (1948), and the 1967–1970 records of Stuckey)

2. Growth habit:
   S=Submersed aquatic species
   E=Emersed (or large floating-leaved) aquatic species

3. Geographical distribution (see text):
   N=Northern
   S=Southern
   W=Widespread

so, the data are limited and incomplete, with many gaps, but these data are the only ones available for evaluation. It is by making comparisons of the present-day flora with the records of the past flora that the changes that have or are occurring in the flora can be determined and documented.

One of the earliest and most comprehensive surveys of the aquatic flowering-plant flora in the United States was conducted at several locations in western Lake Erie in 1898 by A. J. Pieters, as part of the United States Fish Commissions' systematic investigation of the biology of the Great Lakes, under the direction of Professor Jacob Reighard of The University of Michigan. The United States Fish Hatchery at the town of Put-in-Bay served as headquarters for this survey,

TABLE 2

Documented information on the vascular aquatic flowering plants recorded in the studies by Pieters, by Core, and by Stuckey, for Put-in-Bay harbor, Lake Erie, Ohio

Species[1]	Pieters' 1898 collections; Pieters (1901)[1]	Core's 1939–1940 collections; Core (1948, 1949)[1]	Stuckey's 1967–1970 collections; notes on abundance 1967–1970[2]
Potamogeton amplifolius Tuckerm.	Put-in-Bay (US); Hatchery Bay	No specimen; Apparently absent	Absent
Potamogeton friesii Rupr.	Put-in-Bay (US); Not abundant, Put-in-Bay	No specimen; Apparently absent	Absent
Potamogeton praelongus Wulf. (as *P. amplifolius* Tuckerm.)	Put-in-Bay (US); No comment	No specimen; Apparently absent	Absent
Potamogeton perfoliatus L. var. *bupleuroides* (Fern.) Farw. (as *P. perfoliatus* L.)	Put-in-Bay (US); Put-in-Bay	No specimen; Apparently absent	Absent
Megalodonta beckii (Torr.) Greene (as *Bidens beckii* Torr.)	Put-in-Bay (US); Squaw Harbor	No specimens; Apparently absent	Absent
Najas guadalupensis (Spreng.) Magnus (as *N. flexilis* var. *robusta* Morong; *N. flexilis* (Willd.) Rostk. & Schmidt)	Put-in-Bay (US); Abundant, Put-in-Bay	No specimen; Apparently absent	Absent
Scirpus expansus Fern. (as *S. sylvaticus* L.)	Day's Pool (MICH), Put-in-Bay (BGSU, OS); Shore of pool on South Bass Island	No specimen; Apparently absent	Absent
Carex aquatilis Wahl. (as *C. stricta* Lam.)	Day's Pool (MICH), Put-in-Bay (US); Pond on South Bass Island near Hatchery	No specimen; Apparently absent	Absent
Potamogeton filiformis Pers.	No specimen; Few, Gibraltar Bar	Put-in-Bay (WVA); Absent from Gibraltar Bar (1949)	Absent
Potamogeton gramineus L. (as *P. heterophyllus* Schreb.)	Gibraltar Bar (US); Principal plant on Gibraltar Bar. Also the specimen, (near Gibraltar Island, 17 Aug 1888, *M. E. Day*, OC)	South Bass (WVA); Absent from Gibraltar Bar (1949)	Absent
Potamogeton natans L.	Put-in-Bay (US); Put-in-Bay	No specimen; South Bass (1948)	Absent
Sagittaria rigida Pursh	Squaw Harbor (MICH, US); Everywhere, Squaw Harbor	Squaw Harbor (WVA); South Bass, Disappeared (1949)	Absent
Potamogeton nodosus Poir. (as *P. lonchites* Tuckerm., in Pieters, and *P. americanus* C. & S., in Core and in Tiffany)	Put-in-Bay (US); Common, Put-in-Bay	No specimen; South Bass (1948)	Absent
Nuphar advena (Ait.) Ait.	No specimen; Common, Squaw Harbor	No specimen; South Bass (1948)	Absent
Potamogeton pusillus L.	Put-in-Bay (MICH, US); Put-in-Bay, abundant in Hatchery Bay	Squaw Harbor (WVA), Put-in-Bay (WVA); Squaw Harbor and Hatchery Bay, but not abundant (1949)	Absent
Potamogeton foliosus Raf.	No specimen; Put-in-Bay	Gibraltar Island (FTSL); Squaw Harbor (1949)	Absent

TABLE 2—(*Continued*)

Species[1]	Pieters' 1898 collections; Pieters (1901)[1]	Core's 1939–1940 collections; Core (1948–1949)[1]	Stuckey's 1967–1970 collections; notes on abundance 1967–1970[2]
Nymphaea tuberosa Paine	Put-in-Bay (US); No comment	No specimen; Small patches, Squaw Harbor (1949)	Absent
Elodea canadensis Michx. (as *Philotoria canadensis* (Michx.) Britt.)	Put-in-Bay (MICH, US); Common, Put-in-Bay, Hatchery Bay	Gibraltar Island (FTSL); Hatchery Bay, but not abundant (1949)	Absent
Najas flexilis (Willd.) Rostk. & Schmidt	Put-in-Bay (MICH, US); Abundant, Squaw Harbor, Hatchery Bay, and Gibraltar Bar	Squaw Harbor (WVA); Squaw Harbor, Hatchery Bay, but not abundant (1949)	Absent
Potamogeton zosteriformis Fern. (as *P. zosteraefolius* Schum., in Pieters, and *P. compressus* L., in Tiffany and in Krecker)	Put-in-Bay (US); Everywhere, abundant, Put-in-Bay, Hatchery Bay	Squaw Harbor (WVA), Put-in-Bay (FTSL); Squaw Harbor, Hatchery Bay but not abundant (1949)	Absent
Typha latifolia L.	No specimen; Everywhere	No specimen; South Bass (1948)	T *7344*; Rare
Nelumbo lutea (Willd.) Pers. (as *Nelumbium luteum* Willd.)	No specimen; Introduced into Squaw Harbor and near fish-hatchery	No specimen; Small patches, Squaw Harbor (1949)	S *4087*, S *7264* (FTSL only); Rare
Potamogeton richardsonii (Ar. Benn.) Rydb. (as *P. praelongus* Wulf., *P. perfoliatus richardsonii* Ar. Benn.)	Put-in-Bay (US); Everywhere, plentiful, Put-in-Bay	Put-in-Bay (WVA), Squaw Harbor (WVA), Oak Point Bar (WVA); Squaw Harbor, but not abundant (1949)	P *4298*, *7336*, H; Rare
Zannichellia palustris L.	Squaw Harbor (MICH, US); Apparently one occurrence	No specimen; South Bass (1948)	T *4062*, F *4071*, *4093*, *4582* (CAN, DAO, OS, PH, SMU, UMO, VDB), S *4089*, P *4801*; Rare
Justicia americana (L.) Vahl. (as *Dianthera americana* L.)	No specimen; Put-in-Bay, thick-growth in Squaw Harbor	No specimen; Thick growth completely vanished, Squaw Harbor (1949)	P *4295*, T *7307*, S; Rare
Carex comosa Boott (as *C. pseudo-cyperus* var. *comosa* Boot)	Squaw Harbor (MICH, US); Seen only in one place, Squaw Harbor	No specimen; Disappeared (1949)	T *4055*; Rare
Scirpus acutus Muhl. (as *S. lacustris* L., in Pieters and *S. validus* Vahl., in Core)	No specimen; Everywhere, [apparently common], Squaw Harbor	No specimen; Occasional, Squaw Harbor (1949)	S *4571*, *5195*; Rare
Scirpus americanus Pers. (as *S. pungens* Vahl.)	Put-in-Bay (US); Everywhere, [apparently common], Squaw Harbor	No specimen; Occasional, Squaw Harbor (1949)	T *4057*, S *4574*, *5193*, P; Rare
Juncus torreyi Coville	Put-in-Bay (US); Squaw Harbor	No specimen; South Bass Bass (1948)	S *4065A*; Rare
Scirpus atrovirens Muhl.	Squaw Harbor (US), Put-in-Bay (US); Not reported	No specimen; South Bass (1948)	T *5188A*; Occasional
Scirpus fluviatilis (Torr.) A. Gray	Days Pool (MICH), Put-in-Bay (US); Everywhere	No specimen; South Bass (1948)	T *4058*, S; Occasional
Rumex verticillatus L.	No specimen; Pool on South Bass Island. Also the specimen, (Put-in-Bay, 18 Aug 1894, *Warrallo Whitney*, OC)	No specimen; South Bass (1948)	T *4059*; Occasional
Sparganium eurycarpum Engelm.	No specimen; Everywhere	No specimen; South Bass (1948)	T *4056*, P *4303*; Occasional
Asclepias incarnata L.	No specimen; Everywhere	No specimen; South Bass (1948)	T *5188C*, S, P; Occasional
Sagittaria latifolia Willd.	No specimen; Squaw Harbor	No specimen; Small colony, Squaw Harbor (1949)	T *5188D*, S, P; Occasional

TABLE 2--(*Continued*)

Species[1]	Pieters' 1897 collections; Pieters (1901)[1]	Core's 1939–1940 collections; Core (1948, 1949)[1]	Stuckey's 1967–1970 collections; notes on abundance 1967–1970[2]
Heteranthera dubia (Jacq.) MacM. (as *H. graminea* Vahl.)	Put-in-Bay (MICH); Everywhere, abundant, Put-in-Bay, Hatchery Bay	Gibraltar Island (FTSL); Put-in-Bay (WVA); Hatchery Bay, but not abundant (1949)'	S *7266*, T *7309*; Occasional
Potamogeton pectinatus L.	Put-in-Bay (US); Everywhere, abundant, Put-in-Bay, Hatchery Bay	Oak Point (WVA); Put-in-Bay (WVA); Squaw Harbor, Hatchery Bay, but not abundant (1949)	T *4060*, S *4088*, P *4299*, *7338*, F; Occasional
Ceratophyllum demersum L.	Put-in-Bay (MICH); Everywhere, common, Put-in-Bay, Hatchery Bay	No specimen; Squaw Harbor, Hatchery Bay, but not abundant (1949)	F *4070*, *4094*, S *4085*, *4581*, *7267*, *7269*, T; Common
Myriophyllum exalbescens Fern. (as *M. spicatum* L.)	No specimen; Everywhere, Put-in-Bay, Squaw Harbor, Hatchery Bay	No specimen; Squaw Harbor, Hatchery Bay, but not abundant (1949)	T *4061*, S *4086*, *7272* (OS, VDB), P *4300*; F, Common
Vallisneria americana Michx. (as *V. spiralis* L.)	Put-in-Bay (MICH, US); Everywhere, Put-in-Bay, Squaw Harbor. Also the specimen, (Put-in-Bay, 12 Aug 1896, *F. D. Kelsey*, OC)	Put-in-Bay (FTSL, WVA), Alligator Bar at Gibraltar Island (WVA); Scarce on Gibraltar Bar; Squaw Harbor, Hatchery Bay, but not abundant (1949)	T *4063*, S *4084*, *4580*, *7268*, P *4090*, *4296*, F; Abundant
Potamogeton crispus L.	First noted by Shawver (1931) for Put-in-Bay harbor. The earliest known specimens are from Squaw Harbor (2 Aug 1939, *Core 7308*, WVA; 31 Jul 1940, *Myers s.n.*, WVA).		F *4067* (OS, PH), S *4083* (NYS, OS), T *7308*, *7341* (NYS, OS), *7342*, P; Common
Butomus umbellatus L. f. *vallisneriifolius* Sagorski	First reported by Core (1941) from Alligator Bar, Gibraltar Island; the earliest collection (the emersed form) is from Hatchery Bay (20 Aug 1936, *Tiffany s.n.*, OS); well established on Alligator Bar (Core, 1949).		F *4091*, P *4297*, *4802*, *7337*; Common; Absent from Alligator Bar
Typha angustifolia L.	Not known when it first appeared in Put-in-Bay harbor, but noted for South Bass by Core (1948); moderate sized clump, Squaw Harbor (Core, 1949).		S *4072*, *4570*, P *4305*; Occasional
Carex frankii Kunth	May have been present at an early date, but no records have become available until 1952 (Put-in-Bay, 30 Jun 1952, *W. Hintz s.n.*, FTSL).		T *5188B*; Rare
Potamogeton berchtoldii Fieber var. *acuminatus* Fieber	First collected in 1959 (Squaw Harbor, Jul 1959, *T. R. Fisher 1828*, FTSL).		T *4064*, S *4086A*, *4569* (NYS, OS, SMU), *7270*, *7271* (FTSL only), F *4092*, P; Occasional
Elodea nuttallii (Planch.) St. John	First collected in 1967 (Fishery Bay, 22 Jun 1967, *R. L. Stuckey 4068*, MICH, OS).		F *4068* (MICH, OS), *4095*, *7345* (BISH, OS), S *7265*, T *7343* (BISH, OS); Occasional
Scirpus validus Vahl.	Some specimens from other localities in western Lake Erie labeled as *S. lacustris* by Pieters and *S. validus* by Core are *S. acutus*. However, *S. validus* may have been in Put-in-Bay at the time of their studies, but no authentic records are known. The report of *S. acutus* as new for the Erie Islands (Stuckey, 1968b) probably should have been given as *S. validus*.		S *4573*, *5194*; Rare

Notes and key to symbols:

1. In column one, names in parentheses are those used by Pieters unless stated otherwise. In columns two and three, the data from the specimens appear before the semicolon, and the information from the literature (Pieters, 1901; Core, 1948, 1949) follows the semicolon for each species.
2. In column four, numbers in italics are the field numbers on herbarium specimens collected by R. L. Stuckey from the following locations: F=Fishery Bay, P=Main harbor of Put-in-Bay, S=Squaw Harbor, and T=Terwilliger's Pond. One specimen of each number is deposited in The Ohio State University Herbarium unless stated otherwise. Duplicates deposited in other herbaria are also noted by herbarium symbols, according to Lanjouw and Stafleu (1964).

and thus, because of its close accessibility, Put-in-Bay harbor was the most thoroughly surveyed locality of the several areas where Pieters did field work. Pieters' paper, *The Plants of Western Lake Erie, with Observations on their Distribution* (1901), has come to be regarded as a classic from the viewpoint of the methods employed, the results obtained, and the classification of the aquatic plants discussed.

Contemporary with Pieters' survey was E. L. Moseley's several years' study, *Sandusky Flora* (1899). Moseley, a science teacher in Sandusky High School from 1889 to 1914, frequently visited the islands and prepared manuscript lists of the plants he observed on the various islands, including the plants in Put-in-Bay harbor. Succeeding significant studies include Earl L. Core's *Flora of the Erie Islands* (1948), based on field work conducted during the summers of 1938–1941, his unpublished manuscript of *Plants of Western Lake Erie, after 50 years* (1949), some of the information of which was later summarized and published by Langlois (1954, p. 97–104). Additional references to aquatic flowering plants in Put-in-Bay harbor appear in papers by Stehle (1923), Kennedy (1923), Shawver (1931), Tiffany (1934, 1937), Krecker (1924, 1939), and Stansbery (1961). Data from all of these surveys are recorded and summarized in Table 1. A recent summary of the general changes in the numbers and kinds of plants in Lake Erie has been prepared by Davis (1969).

Additional information comes from specimens deposited in several herbaria, namely Moseley's collections at Bowling Green State University (BGSU); Core's collections at West Virginia University (WVA); Core's collections, the author's collections, and collections of various investigators since 1940 at the Franz Theodore Stone Laboratory (FTSL); Pieters' collections at The University of Michigan (MICH) and at the United States National Museum (US); and Moseley's collections and the author's collections at The Ohio State University (OS). These data are recorded in Table 2.

PUT-IN-BAY HARBOR

Put-in-Bay harbor is a semicircular inlet on the north shore of South Bass Island, Ottawa County, Ohio. Gibraltar Island forms a natural breakwater

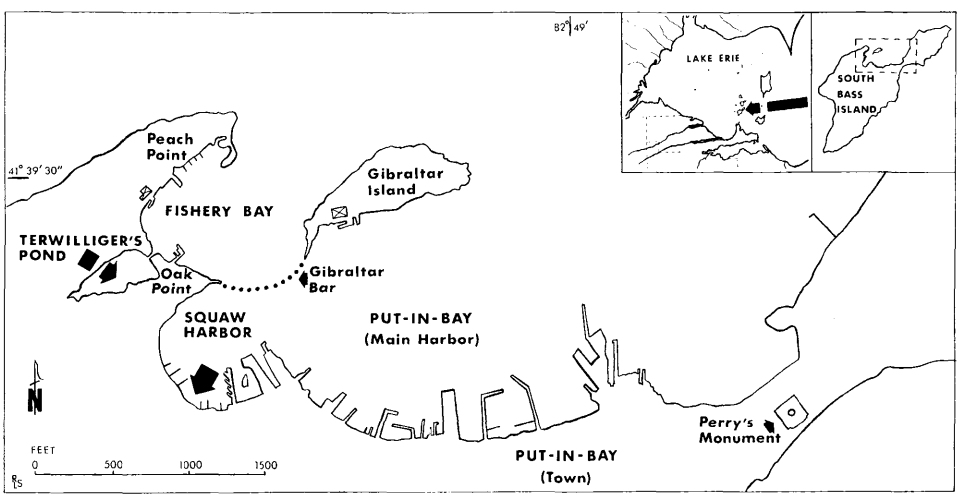


FIGURE 1. Outline map of Put-in-Bay harbor (from U. S. Lake Survey, 1966), showing the sub-inlets: Main harbor of Put-in-Bay, Squaw Harbor, Fishery Bay, and Terwilliger's Pond, along the north shore of South Bass Island, western Lake Erie, Ohio. The large arrow in Squaw Harbor represents the location of the photographs in figures 3 and 4. The location of the laboratory buildings at Stone Laboratory on Gibraltar Island and Peach Point are marked with an X.

which reduces wave and wind action from the north, making the harbor a quiet-water zone. The harbor is composed of three separate sub-inlets: the main harbor (simply called "Put-in-Bay" by Pieters) to the east, Squaw Harbor (called Square Harbor by some) in the middle, and Fishery Bay (called Hatchery Bay by Pieters) to the west, with Terwilliger's Pond (formerly called Day's Pool) extending inland to the southwest from Fishery Bay (fig. 1).

METHODS AND RESULTS OF THE 1967–1970 STUDY

From the field work in Put-in-Bay harbor during the summer months of 1967–1970, 27 species of vascular aquatic flowering plants were recorded, of which 20 had been noted by Pieters (1901). Sampling of submersed aquatics was carried out by dredging of the bottom with a grappling hook from a row boat. Based on the number of times different submersed species were caught on the hook and from observations of both submersed and emersed aquatic plants from the boat and the shore, an estimate of the abundance of these plants in Put-in-Bay harbor was made, according to the following definitions.

Abundant (A)—Plants in large numbers and dominant; at few or many study sites.

Common (C)—Plants in large numbers, but generally not appearing dominant; occurring in many places, usually at most of the sites studied.

Occasional (O)—Plants few in number; usually seen at more than two study sites, but not at all of the study sites.

Rare (R)—Plants few in number at one or two study sites.

These definitions explain the meanings of these abundance terms as given in Tables 1, 2, 3, and 5.

The names of all species present in the habor and the estimated abundance value of each are recorded in Table 1. Table 2 contains the documentation of these species—the field numbers of the voucher herbarium specimens and the herbaria where these and other known specimens from previous studies have been deposited, following the herbarium abbreviations given in Lanjouw and Stafleu (1964).

The overall geographical distributions of these species appeared to be important. Therefore, the geographical distribution of each of the original 40 species of Pieters' survey was determined by consulting published maps or notations concerning distribution in monographs, revisions, floras, and/or manuals. From these data three basic distributional patterns emerged, defined as follows.

Northern (N)—Distribution mostly to the north of Lake Erie, and extending to the west and/or east.

Southern (S)—Distribution mostly to the south of Lake Erie, and extending to the west and/or east.

Widespread (W)—Distribution both to the north and south of Lake Erie, and extending mostly throughout eastern United States or throughout North America.

As used here, these terms are defined without relation to the geographical origin of the species.

CHANGES IN THE AQUATIC PLANT FLORA

The changes in the vascular aquatic flowering-plant flora in Put-in-Bay harbor have been drastic. Pieters (1901) reported 40 species of submersed, floating-leaved, and emersed rooted species. Of these, eight species (or 20% of the flora) were never reported in later surveys. By 1949, at the time of Core's survey, 14 species (or 35% of the flora) had dropped out. Today only 20 species remain.

Of the original 40, nine species are now considered to be rare, eight occasional, two common, and only one abundant (Table 1). By studying the data on abundance for individual species as given by Pieters (1901), by Core (1949), and by myself, a gradual decrease in abundance is indicated by the use of such terms as "plentiful," "common," and "abundant" by Pieters, compared with the use of terms such as "occasional" and "rare" to designate the present size of the populations (Table 1). For example, *Potamogeton richardsonii*, once "plentiful" according to Pieters, is now "rare." The use of these terms to denote abundance is relative and depends on the author's definitions of them; unlike the present work, Pieters does not provide definitions, so the terms are probably not entirely comparable. *Ceratophyllum demersum*, *Myriophyllum exalbescens*, and *Vallisneria americana*, which were reported by Pieters to be common or abundant and are also considered to be common or abundant today, are probably not as abundant as they were in 1898.

A major portion of the record of these floristic changes is preserved in Pieters' (1901) description of the plant communities in Squaw Harbor, in the main harbor of Put-in-Bay, and in Fishery Bay, and also in Core's account (1949) of the flora of these places 50 years later. As an aid to envisioning these changes, excerpts dealing with each of these three sections of Put-in-Bay harbor quoted from these two authors are given below, together with an additional source (Tiffany 1934, 1937) on Squaw Harbor and comparable data on the occurrence and abundance of the plant species from the 1967–1970 study. Current accepted plant names, where different from those of Pieters, Core, or Tiffany, are inserted in brackets following the older name in the quoted text, or they can be determined by consulting Table 2.

Plants in Squaw Harbor

According to Pieters (1901, p. 61),

> Squaw Harbor is a shallow body of water averaging about 4 feet in depth and not exceeding 7 feet in the deepest part, with a rocky border which prevents a swamp [marsh] formation of any extent. . . . The mud bottom slopes gradually and is covered with a dense mass of vegetation. From the entrance of Squaw Harbor to the end of Gibralter Island the water becomes gradually deeper, but does not exceed a depth of 15 feet, and reaches that depth only near the end of Gibraltar Island. The bottom changes as gradually from mud to clay, with some sand and gravel along the shore.
>
> A bar separates Squaw Harbor from Hatchery Bay [Fishery Bay], which is also shallow, nowhere over 11 feet deep and averaging perhaps 5 feet. The bottom of this bay varies much, being stony in some places and muddy in others. The water is turbid, and it is usually impossible to see plants more than 2 to 3 feet below the surface.
>
> Squaw Harbor is bordered by a narrow strip of rush-like plants. These plants are limited abruptly on the land side by the rocks and on the other side by a depth of from 2 to 2.5 feet of water. Toward the east *Sagittaria rigida* forms a prominent group, extending about 30 feet from the shore and finding its limit of depth in about 2.5 feet of water. . . . [p. 62] This species also occurs on the other shore with *Scirpus lacustris* [*S. acutus*], but is not as abundant as on the east side. Wherever *Sagittaria rigida* and *Scirpus lacustris* [*S. acutus*] occur together the former always occupies the deeper water. Near the shore *Typha latifolia*, *Carex pseudo-cyperus* var. *comosa* [*C. comosa*], and species of *Scirpus* form a background for the *Sagittaria*.
>
> *Scirpus lacustris* [*S. acutus*] is scattered along the east shore, but is not as abundant as on the other side, a few hundred feet away, where *Scirpus pungens* [*S. americanus*] is the prevailing species. . . . Along the south shore there is a thick growth of *Dianthera* [*Justicia*] *americana*, and the shallow water of the harbor is filled with submersed forms, of which *Vallisneria spiralis* [*V. americana*], *Myriophyllum spicatum* [*M. exalbescens*], *Naias flexilis*, *Ceratophyllum demersum*, and the various species of *Potamogeton* are the principal ones. . . . A patch of *Nuphar advena* and one of *Nelumbium luteum* [*Nelumbo lutea*], the latter but recently established, occupy part of the head of the harbor. . . .

In the 1930's, Tiffany (1934, p. 5; 1937, p. 914) wrote that, in Squaw Harbor,

> The water is shallow, is much protected from winds, and in late summer may become choked with such aquatic flowering plants as *Potamogeton americanus* [*P. nodosus*], *P. pectinatus*, *P. compressus* [*P. zosteriformis*], *Elodea canadensis*, *Naias flexilis*, *Val-*

lisneria spiralis [*V. americana*], *Ceratophyllum demersum*, *Myriophyllum spicatum* [*M. exalbescens*], *Scirpus validus* [? *S. acutus*], and *Nelumbo lutea* [(figs. 2 and 3)].

Fifty years after the time of Pieter's study, Core (1949, p. 2) noted that in Squaw Harbor the mud bottom continued to slope gradually and was "still cov-

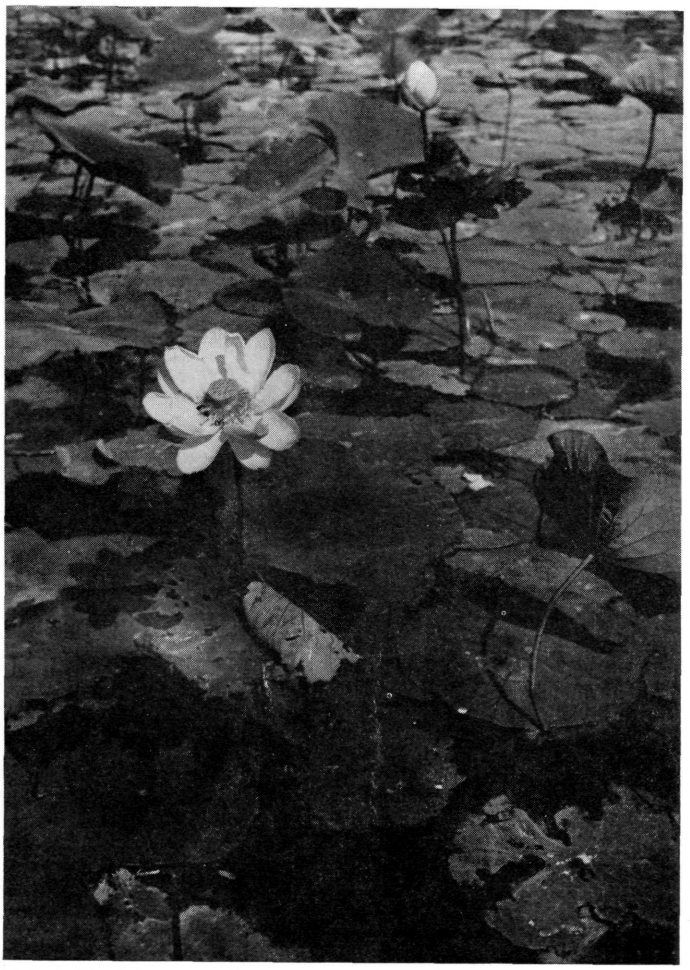


FIGURE 2. Large colony of *Nelumbo lutea* (water lotus) in Squaw Harbor. Photograph by Clarence E. Taft, Summer 1938. Only three small plants were in Squaw Harbor in 1967 and in 1968.

ered with a dense mass of vegetation." The turbidity "seems to have increased appreciably." He noted further:

> The shores of Squaw Harbor are now almost completely lined with boat docks and more continue to be built. This has almost eliminated the narrow strip of rush-like plants that fringed the shores in 1898. Only occasional plants of *Scirpus validus* [*S. acutus*] and *S. americanus* still occur. *Sagittaria rigida* . . . [p. 3] has now apparently completely disappeared. . . . [It was] present as late as 1940, [but] its disappearance may have been partly due to the high water of 1943–48 and partly due to increasing activity about the numerous docks in the locality. . . . *Carex comosa* has likewise disappeared. . . . The "thick growth" of *Dianthera* [*Justicia*] *americana* along the south shore has completely disappeared.

On the other hand, the submersed forms remain in great abundance and with virtually identical composition, filling the shallow water by the middle of August. *Vallisneria americana*, *Myriophyllum exalbescens*, *Naias flexilis*, *Ceratophyllum demersum* and various species of *Potamogeton*, including *P. crispus* [invaded in the 1930's], *P. foliosus*, *P. pectinatus*, *P. pusillus*, *P. richardsonii*, and *P. zosteriformis*, are the principal representatives. Small patches of *Nelumbo lutea* and *Nymphaea tuberosa*, both of these greatly reduced in amount by the recent high water, still persist. *Zannichellia palustris* is found rarely. *Anacharis* [*Elodea*] *canadensis* is common. *Heteranthera dubia*, not noted [from Squaw Harbor] by Pieters, occurs in some abundance.

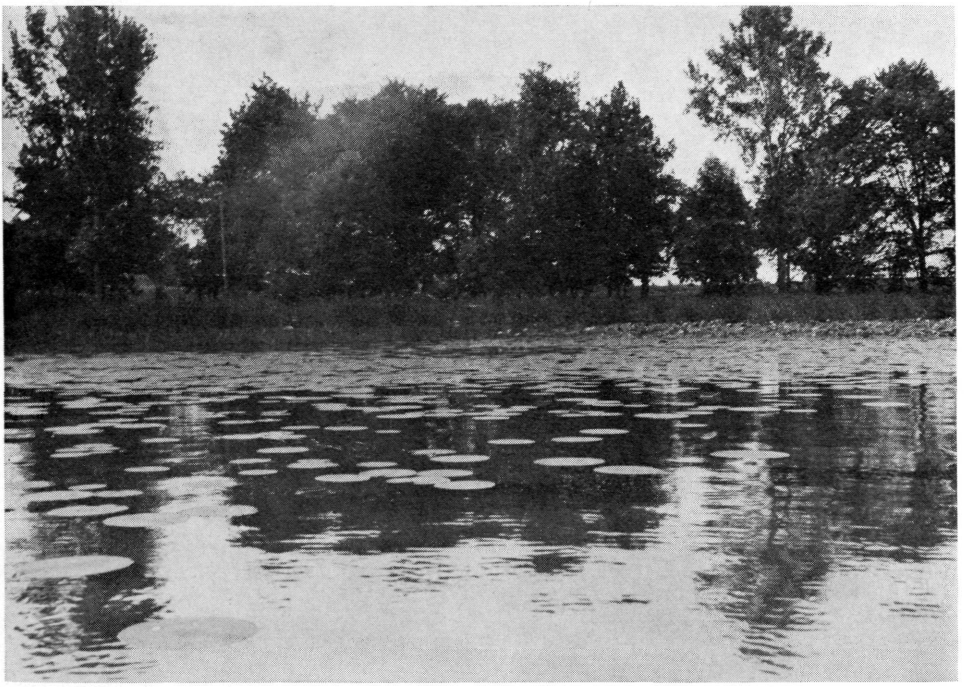


FIGURE 3. Aquatic vegetation in Squaw Harbor looking toward the southwest shoreline. Note floating-leaved plants in the foreground and dense zones of cat-tails and sedges in the background. Photograph by Clarence E. Taft, Summer 1938.

During the summers of 1967 and 1968, thirty years later than Core's study, *Vallisneria americana* was the most abundant species in Squaw Harbor. *Myriophyllum exalbescens*, *Potamogeton crispus*, and *P. pectinatus* were common, whereas *Ceratophyllum demersum* was occasional in 1967, but was more common in 1968. *Zannichellia palustris* and *Heteranthera dubia* were rare, but *Potamogeton foliosus*, *P. pusillus*, *P. richardsonii*, *P. zosteriformis*, *Najas flexilis*, *Elodea canadensis*, and *Nymphaea tuberosa* had disappeared. Very small colonies of *Sagittaria latifolia*, *Scirpus americanus*, *S. validus*, *S. acutus*, *S. fluviatilis*, *Typha angustifolia*, and *Juncus torreyi* occurred on the southwest shore in 1967–1968 (fig. 4), but all of these species have now disappeared from this location, probably because of the high water in 1969 and 1970 and because of the increased use of that shore by boat traffic. Three small plants of *Nelumbo lutea* were found in deep water in 1967 and in 1968. A very small colony of *Justicia americana* continues to survive along the west shore, but no longer in the thick growth described by Pieters. Only two submersed species, *Potamogeton berchtoldii* and *Elodea nuttallii*, are new to Squaw Harbor. Considerable dredging of Squaw Harbor occurred during the low-water-level period in the early 1960's, and with the rise of the water in the

late 1960's, many more docks and retaining walls were built (fig. 5), such that the entire shore, except for the small portion of the harbor which is shown in figure 4, is now lined with these structures.

Plants in the Main Harbor of Put-in-Bay and on Gibraltar Bar

According to Pieters (1901, p. 62),

> The same species that flourish in Squaw Harbor extend out [eastward] into the main bay [main harbor of Put-in-Bay] to a depth of 10 feet or a little more. Every-

FIGURE 4. Aquatic vegetation in Squaw Harbor looking toward the southwest shoreline. Note absence of floating-leaved plants and only a few remaining cat-tails and sedges, all of which had disappeared from this location by the summer of 1970. Photograph by Ronald L. Stuckey, August 1968.

> where from Gibraltar Island to the shore of South Bass Island the bottom of the bay is covered, generally thickly, with plants of which *Naias flexilis* and var. *robusta* [*N. guadalupensis*], [p. 63] *Vallisneria spiralis* [*V. americana*] and *Heteranthera graminea* [*H. dubia*] are most abundant, but *Ceratophyllum demersum*, *Myriophyllum spicatum* [*M. exalbescens*], *Potamogeton zosteraefolius* [*P. zosteriformis*], *P. perfoliatus*, *P. perfoliatus richardsonii* [*P. richardsonii*], *P. pectinatus*, and *Elodea canadensis* are also plentiful. . . .
>
> . . . In the deeper water just east of the bar [extending from Gibraltar Island to South Bass Island] the vegetation is most luxuriant, great quantities of *Naias* and of *Vallisneria*, with other species being brought up at every cast of the grapple. . . . Besides the *Vallisneria* [which is also on the bar] the principal plant on the bar is *Potamogeton heterophyllus* [*P. gramineus*], and this I did not find elsewhere in the bay except in one wave-washed place on the south shore. This species flourishes all along the bar, but especially toward the Gibraltar end, where it is accompanied by a few plants of *Potamogeton filiformis* and a dwarf form of *Naias flexilis* with close, compact habit and strong root system. . . .

In the bay between Gibraltar Island and South Bass Island, the main harbor of Put-in-Bay, Core (1949, p. 4) noted that "almost nothing grows in this area today, perhaps because of the increased turbidity and activity of boats." He further wrote:

> The bar . . . has likewise lost the abundant vegetation reported by Pieters. *Naias* and *Vallisneria* . . . are now scarce and . . . [*Potamogeton gramineus* and *P. filiformis* are] not found at all. . . .

A significant addition to the flora of the bar is *Butomus umbellatus* f. *vallisneriifolius*, a sterile deep-water form of the flowering rush with long leaves the ends of which may float on the surface, the roots well established in the layer of pebbles and cobblestones which cover the bar [see also Core (1940) and Gaiser (1948, p. 387)].

In 1967–1968, in the bay south of Gibraltar Island, near the docks at Stone Laboratory, *Vallisneria americana* occurred in the greatest abundance, with *Myriophyllum exalbescens* and *Ceratophyllum demersum* occasional, and *Potamogeton berchtoldii* rare. No other submersed species of aquatic plants were found in this part of the bay. No plants grew on the bar, but small colonies of *Myriophyllum exalbescens* and *Potamogeton richardsonii* have been found on the Fishery Bay side of the bar. *Butomus umbellatus* has disappeared entirely from this location (Stuckey, 1968a).

FIGURE 5. West corner of Squaw Harbor showing extent of habitat destruction by man. Boat dock and retaining wall built in 1967. Photograph by Ronald L. Stuckey, August 1968.

Plants in Fishery Bay

Pieters (1901, p. 63) noted that:

In Hatchery Bay [Fishery Bay] the narrow-leaved *Potamogetons*, such as *P. pusillus*, *P. zosteraefolius* [*P. zosteriformis*], and *P. pectinatus*, with *Heteranthera graminea* [*H. dubia*] and *Naias flexilis*, are especially abundant, and in quiet places on muddy bottom *Ceratophyllum demersum*, *Myriophyllum spicatum* [*M. exalbescens*], and *Elodea canadensis* are common.

Core (1949, p. 4) wrote that the plants in Hatchery Bay [Fishery Bay]

. . . are now scattered in patches, the location of which apparently varies from year to year. No significant difference was noted in the inventory of species, which Pieters reported. . . . However, Pieters recorded those species as "abundant" or "common" in 1898, whereas they can scarcely be so regarded at the present time, except near the shores. . . . Increased turbidity and increased boat activity have doubtless been instrumental in lowering the plant populations.

In 1967 and 1968, the submersed aquatic plants were most prevalent in the shallow water south of the dock at the Fisheries Building of Stone Laboratory along the west shore. In this portion of Fishery Bay, *Vallisneria americana*, *Myriophyllum exalbescens*, *Ceratophyllum demersum*, and *Potamogeton crispus* were

all common to abundant. Newcomers to the bay since Core's study are *Elodea nuttallii* and *Potamogeton berchtoldii*, both of which were rare. In the open portion of Fishery Bay, only the first four named species were found. However, of those four, the first three species are probably not as abundant as formerly. Certainly the colonies of *Vallisneria americana* are not as dense as the one illustrated by Langlois (1954, p. 36, fig. 7), nor do the plants have the retarding and reducing effect on the waves in Fishery Bay as commented upon by him (Langlois, 1965, p. 342).

Possible Reasons for the Changes in the Aquatic Plant Flora

Over the past 70 years, various environmental changes have occurred in Lake Erie. A gradual warming of the waters, represented by an increase in mean annual temperature of approximately 2°F since 1918–1928, has been reported by Beeton (1961). Oxygen in the bottom waters now becomes depleted in certain months during long periods of calm water over large areas (Carr, 1962; Britt, Skoch, and Smith, 1967), and there doubtless has also been a decrease in oxygen content near lakeshore waste outlets in the more shallow waters—the habitats where aquatic plants once grew in abundance. Langlois (1944, 1954) and Verduin (1964) have both noted the increase in turbidity of western Lake Erie waters, although Verduin (personal communication, 1968) and Britt (personal communication, 1971) now believe that turbidity in the lake has decreased somewhat in recent years. Man's influence on the lake has been summarized by Verduin (1969).

Turbidity in Put-in-Bay Harbor

In his 1898 study, Pieters (1901) commented that the water was turbid in Put-in-Bay harbor and about the island area, compared to other sampling sites where he had found the water to be quite clear. Hudgins (1943, p. 29) explained this local turbidity by pointing out that the "rows of the vineyards are arranged in straight lines and too frequently in the direction of the slope." Cultivation between the rows further facilitates erosion. Hudgins also noted that he had observed "on more than one occasion after rains . . . the yellow color signifying the silt of the waters of Squaw Harbor, Put-in-Bay, advance from the shore finally to cover the bay." In the spring before the very summer that Pieters did his survey and reported on the turbidity of the harbor waters, Thorndale (1898) wrote that "there was no end of complaint about mud and water standing ankle deep in the vineyard rows." The turbidity of Lake Erie waters has been studied by Chandler (1947). In general, the more turbid the water, the less effectively light will penetrate through it, which in turn is sufficient to retard photosynthesis.

The relationship of turbidity, depth, and apparent photosynthesis in selected species of submersed aquatic plants in the island area of western Lake Erie was studied in the late 1930's and early 1940's by Meyer and his students (Meyer and Heritage, 1941; Meyer, Bell, Thompson, and Clay, 1943). With the water at minimum turbidity, they measured the apparent photosynthesis in plants of *Ceratophyllum demersum* (Meyer and Heritage, 1941), and of *Najas flexilis*, *Elodea canadensis*, *Potamogeton richardsonii*, *Heteranthera dubia*, and *Vallisneria americana* (Meyer, Bell, Thompson, and Clay, 1943), each submerged at a series of depths ranging down to 10 meters. They also measured the compensation point, defined as the light intensity at which apparent photosynthesis is equal to zero (photosynthesis minus respiration), which was expressed as depth in meters that each plant was submerged. Below this depth a species probably would not survive.

When Lake Erie water attained approximate maximum turbidity, Meyer and Heritage (1941) noted that the apparent photosynthesis in *Ceratophyllum demersum* was markedly reduced. "With the water at approximately the minimum tur-

bidity attained during the summers of 1937 and 1938, the compensation point was at a depth of between eight and ten meters; when the water was at approximately the maximum turbidity attained during these two summers the compensation point was at a depth of between one and two meters [p. 22]." From the results of their study it becomes apparent that, with increased turbidity, the compensation point is at an increasingly more shallow depth, and therefore, if high turbidities are maintained, plants normally occupying deeper water will die. The compensation points of all of the species they studied, except *Najas flexilis* and *Vallisneria americana*, were between eight and ten meters under conditions of minimum turbidity. The compensation point of *Najas flexilis* was determined to be between eight and ten meters, but, because this determination was made on a day when the lake water was less turbid than it had been when the other species were studied, this species was believed by them actually to have a compensation point at a shallower depth. Meyer, Bell, Thompson, and Clay (1943) concluded that, under conditions permitting approximately maximum penetration of light into the waters of western Lake Erie, all of the species studied, except possibly *Najas flexilis*, could survive, although not necessarily grow, at depths of as much as eight meters. They also concluded that *Vallisneria americana*, which had very appreciable photosynthesis at a depth of 10 meters, could survive at somewhat greater depths than the other species investigated, implying that, as turbidity increased, this species could continue to survive at greater depths than could the other species studied.

A comparison of the results of these 30-year old studies with the present abundance of these same species in Put-in-Bay harbor (Table 3) shows that *Najas flexilis*, which had the lowest compensation point, has disappeared from the bay. *Elodea canadensis* has also disappeared. *Potamogeton richardsonii* is rare, *Heteranthera dubia* is occasional, and *Ceratophyllum demersum* is common. *Vallisneria americana*, which could survive at the lowest light intensity, is by far the most abundant species in the bay today, growing at the greatest depths. Thus, over the years, increased turbidity and the resultant reduced amount of light penetration appear to have caused either a reduction in or elimination of the species determined by Meyer and his students to have shallower compensation points and higher light requirements.

TABLE 3

Comparison of compensation points of submersed species of vascular aquatic plants (after Meyer et al., 1941, 1943) with present-day abundance

Species	Compensation point in meters depth	Presdent-day abundance
Najas flexilis	Above 8	Disappeared
Elodea canadensis	8–10	Disappeared
Potamogeton richardsonii	8–10	Rare
Heteranthera dubia	8–10	Occasional
Ceratophyllum demersum	8–10	Common
Vallisneria americana	Below 10	Abundant

Observations on the occurrence or absence of certain species in Terwilliger's Pond during the summer months of 1967–1970 also suggest that turbidity may be a limiting factor. In 1967, *Potamogeton crispus*, *P. pectinatus*, *P. berchtoldii*, *Myriophyllum exalbescens*, and *Vallisneria americana* were present in the shallow water along the northwest side of the pond. These species were also present there in 1968 and in greater abundance than in 1967. In addition, *Ceratophyllum*

demersum, *Elodea nuttallii*, and *Heteranthera dubia* had invaded; these three, along with *Potamogeton crispus* and *Myriophyllum exalbescens*, were present in the shallow, relatively clear water at the west end of the pond, where none of these species had been present the previous year. With the one-to-two-foot rise of water level in Lake Erie in the summer of 1969, considerable erosion had occurred along the south bank, which by the summer of 1970 had washed away at least two feet of the bank (causing increased turbidity of the water), and at which time no species of submersed aquatic plants were found in Terwilliger's Pond. A few species, *Vallisneria americana*, *Myriophyllum exalbescens*, and *Ceratophyllum demersum*, had persisted in small amounts in some parts of the pond in 1969, but were not present in the shallow water at the west end.

It is noteworthy that, of the species no longer present in Put-in-Bay harbor, most have a similar over-all geographical distribution (Tables 1 and 4). Of the eight species which have never been found since Pieters' survey, five are northern

TABLE 4

Summary of the geographical distributions of the original 40 species of vascular aquatic plants in Put-in-Bay harbor (summarized from Table 1)

Total number of species that	General Geographical Distributions			
	Northern	Southern	Widespread	Total
Disappeared before 1940	5	2	1	8
Disappeared before 1949	9	4	1	14
Disappeared before 1967	11	5	4	20
Have survived since 1898	3	3	14	20
Total number of submersed species that				
Disappeared before 1967	10	2	3	15
Have survived since 1898	1	0	6	7

species, and of the total of 20 species that have disappeared, 11 are northern in distribution, where they are particularly common in cool-water lakes. An even more striking comparison is provided by considering only those species which are submersed, a total of 22, of which 15 have been lost. Ten of these 15 are northern species.

Many of these northern species reach or once reached the southern boundary of their total distribution in the northern part of Ohio in Lake Erie and nearby waters. The early drop-out of a high percentage of species occurring locally in Put-in-Bay harbor, but which are common in the cool, clear, well-oxygenated waters of the north, has probably come about owing to a combination of gradual warming, increased turbidity, and decreased oxygen content of the waters in Lake Erie. These species can be considered as a group having apparently narrow ecological tolerances. Of the original 20 species that have continued to survive, 14 (70%) have widespread distributions. Of these 20 species, only seven are submersed species, of which six (*Heteranthera dubia*, *Zannichellia palustris*, *Potamogeton pectinatus*, *Ceratophyllum demersum*, *Myriophyllum exalbescens*, and *Vallisneria americana*) have a widespread distribution. These widespread species occur in warmer, more turbid, more poorly oxygenated waters, suggesting that they have wider ecological tolerances. Only one submersed, northern species, *Potamogeton richardsonii*, survives in Put-in-Bay harbor today (Tables 1 and 4).

Man's Use of the Harbor

Another very significant reason (besides turbidity) for the reduction and elimination of the vascular aquatic flowering plants of Put-in-Bay harbor has been man's use of the bay. Located on this harbor is the town of Put-in-Bay. Over the years Put-in-Bay has become the major resort town on the Erie Islands, attracting tourists from all over the country (Langlois and Langlois, 1948). Many of these tourists come by boat, and consequently over the years the bay has become lined with a series of docks to accomodate lake-size pleasure crafts, sailboats, motor boats, and even rowboats. In order to accomodate the larger boats, the shallower portions of the bay have been dredged in many places, docks have been built, and retaining walls of concrete and/or steel have been constructed. The former ideal shallow-water shore habitats with bottoms gradually sloping from the shore to the deeper portions of the bay have virtually been eliminated and replaced with deep muddy channels. Species with narrow ecological tolerances and distributions limited to these once-shallow, once-more-clear water areas have been destroyed, while other species with wider ecological tolerances have been able to recolonize the dredged and muddy areas and to survive in areas more physically disturbed by man's actions. Continued and increasing use of motor boats that tear apart and uproot submersed plants and release exhaust gases and oil into the water must also have detrimental effects on the aquatic flowering plants, creating conditions under which only a few tolerant species, such as *Vallisneria americana*, *Myriophyllum exalbescens*, *Ceratophyllum demersum*, *Potamogeton crispus*, and *P. pectinatus* can exist. Additional sources of deleterious wastes in Put-in-Bay harbor come from the dumping of domestic sewage into the water and the runoff from agricultural land. All of the above-mentioned conditions must be taken into consideration as possible interrelated factors that have, in part or in total, contributed to this 50% loss in species composition of Put-in-Bay harbor.

It is clearly evident, therefore, that the amount of biological diversity, as represented by aquatic vascular plants, has been drastically reduced in Put-in-Bay harbor, such that only five submersed species, *Vallisneria americana*, *Myriophyllum exalbescens*, *Ceratophyllum demersum*, *Potamogeton crispus*, and *Butomus umbellatus* f. *vallisneriifolius* can be considered common or abundant today. Only the first three of these five were in the original 40. On the other hand, during the same 70-year period, only four submersed aquatic species, *Potamogeton crispus*, *P. berchtoldii*, *Elodea nuttallii*, and *Butomus umbellatus* f. *vallisneriifolius*, have invaded Put-in-Bay harbor, an invasion which took place sometime within the past 40 years.

COMPARISON WITH OTHER AQUATIC HABITATS ON THE ISLANDS

Records of the aquatic flora from other localities on or around the islands with which the Put-in-Bay harbor flora may be compared are not as complete as are those of Put-in-Bay harbor. Probably no other bay about the islands had as diverse an aquatic flora as did Put-in-Bay harbor.

In any attempt to compare the aquatic flora of Put-in-Bay harbor with those of other aquatic sites on the islands, there is the problem of different types of habitats. These habitats are essentially of two kinds: (1) the bays, such as the main harbor of Put-in-Bay, Squaw Harbor, Fishery Bay, and Terwilliger's Pond on South Bass Island; Manila Bay on North Bass Island; and North Bay on Kelleys Island, all of which are open or in contact with the lake; and (2) the shallow ponds behind gravel or sand bars, such as Carp Pond on Kelleys Island, Haunck's Pond on Middle Bass Island, Smith's Pond and Fox's Marsh on North Bass Island, and the North Lagoon and Fox's Pond on Pelee Island (Canada). Most of these ponds have had much less disturbance by man than has Put-in-Bay harbor.

Considering only the submersed and the unattached floating aquatic vascular plants on the Erie Islands, a total of 28 species are present. Of these 28 species,

14 occur only in the ponds, six occur only in the bays, and eight occur in both ponds and bays (Table 5). Of these 28 species, eight have apparently become established recently, leaving 20 as the original total number of species. Since 1900, 10 (50%) of these 20 species have disappeared. Of those 10, four have disappeared since 1940. Thus, when the species of aquatic plants in all of the bays and ponds are considered, the percentage lost is very similar to those lost at the single locality of Put-in-Bay harbor. Of the original 15 species that occurred only in bays, only five (33%) have survived and 10 (67%) have disappeared. However, it is only species restricted to bays that have incurred such high extirpation. The changes can best be explained by noting the great extent of the influence of man on the flora of the bays, as previously described for Put-in-Bay harbor. In contrast, the ponds (with the exception of Haunck's Pond) have been little influenced by man, at most by surface wash from adjacent cultivated fields. Floristically, these ponds are essentially the same today as they were 70 or more years ago.

TABLE 5

Summary of the abundance and changes among the sumbersed and the unattached floating vascular aquatic plants on the islands in western Lake Erie since about 1900

Number of species	Ponds only	Bays only	Bays + Ponds	Total
Present today	14	6	8	28
Recently established	4	1	3	8
Disappeared since 1900	0	10	0	10
Disappeared since 1940	0	4	0	4

Species[1]	Isolated Ponds[2]	Bays[2]
I. Species that are present today		
**Ceratophyllum echinatum*	rare	
Lemna minor	common	
Lemna trisulca	common	
Najas flexilis[3]	rare	
**Najas marina*	rare	
Potamogeton foliosus[3]	occasional	
**Potamogeton berchtoldii* var. *berchtoldii*	rare	
**Potamogeton strictifolius*	rare	
Ranunculus longirostris	occasional	
Spirodela polyrhiza	common	
Utricularia gibba	rare	
Utricularia resupinata	rare	
Utricularia vulgaris	common	
Wolffia columbiana	occasional	
**Elodea nuttallii*		occasional
Heteranthera dubia		rare
Potamogeton filiformis		rare
Potamogeton nodosus		rare
Potamogeton richardsonii		occasional
Vallisneria americana		abundant
**Butomus umbellatus* f. *vallisneriifolius*	occasional	common
Ceratophyllum demersum	common	occasional
Elodea canadensis	common	occasional
Myriophyllum exalbescens	occasional	common
**Potamogeton berchtoldii* var. *acuminatus*	occasional	occasional
**Potamogeton crispus*	occasional	common
Potamogeton pectinatus	common	common
Zannichellia palustris	occasional	occasional

TABLE 5—(*Continued*)

Species	Isolated Ponds	Bays
II. Species that have disappeared[4]		
Megalodonta beckii		present
Najas guadalupensis		abundant
Potamogeton amplifolius		present
Potamogeton friesii		not abundant
†*Potamogeton gramineus*		common
†*Potamogeton natans*[3]		present
Potamogeton perfoliatus		present
Potamogeton praelongus		present
†*Potamogeton pusillus*		abundant
†*Potamogeton zosteriformis*		abundant

Notes and keys to symbols:

1. * Species that have appeared in recent years (not reported in previous surveys); † species that have disappeared since the period, 1940–1950.
2. Localities studied:
   a. Ponds (closed to the lake)
      Carp Pond, Kelleys Island
      Fischer's Pond, Middle Bass Island
      Fox's Marsh, North Bass Island
      Fox's Pond, Pelee Island
      Haunck's Pond, Middle Bass Island
      North Lagoon, Pelee Island
      Quarry Pools, Kelleys Island
      Smith's Pond, North Bass Island
   b. Bays (open to the lake)
      Fishery Bay, South Bass Island
      Manila Bay, North Bass Island
      North Bay, Kelleys Island
      Main harbor of Put-in-Bay, South Bass Island
      Squaw Harbor, South Bass Island
      Terwilliger's Pond, South Bass Island
3. *Potamogeton natans* also grew in the ponds according to Core (1948). One specimen is known from Haunck's Pond (31 Jul 1939, *Core s.n.*, WVA). *Najas flexilis* and *Potamogeton foliosus* formerly grew in the bays.
4. Information on abundance of species that have disappeared is taken or inferred from Pieters (1901).

COMPARISONS WITH THE AQUATIC FLORA OF OTHER LAKES

Lake East Okoboji, Iowa

Changes in the vascular aquatic flowering plant flora of Lake East Okoboji, Dickinson County, Iowa, were reported by Volker and Smith (1965), who compared the results of their survey in 1961 with one made in 1915. Their study showed that, during the 46 years between these two studies, 26 of the original 44 species, or 60% of the aquatic flora, had disappeared. The reduction in the submersed species was especially striking, for 18 of 23 species were lost. They discussed several conditions affecting these changes in the flora, among which were the intense use of the surrounding land for agriculture and the exploitation of the lake and its shore by man's activities. These uses have led to increased siltation and turbidity from the cultivation and runoff from the land, and increased nutrient content of the water from domestic sewage from the growing human population.

The changes that have occurred in Lake East Okoboji are remarkably similar to those in Put-in-Bay harbor, both in terms of the kinds of species that have disappeared and the kinds that have survived. At the time of the earliest surveys, these lakes had 18 species of submersed aquatic plants in common. In both lakes eleven of these have disappeared, and of these eleven, eight are northern species characteristic of cool, clear-water lakes (Table 6). *Potamogeton richardsonii*, the only northern submersed species that survives in Put-in-Bay harbor, is also still present in Lake East Okoboji. The total number of species that have disappeared from Lake East Okoboji is even greater than in Put-in-Bay harbor. Even some

of the common, more tolerant, generally widespread species, such as *Myriophyllum exalbescens*, *Heteranthera dubia*, and *Elodea nuttallii*, which are present in Put-in-Bay harbor, have disappeared from Lake East Okoboji. The most abundant species in Lake East Okoboji in 1915, *Ceratophyllum demersum*, a widespread species common in Put-in-Bay harbor today, was found at only two East Okoboji stations in 1961. This situation suggests that the ecological conditions of Lake East Okoboji are worse than in Put-in-Bay harbor. Among the other widespread, submersed aquatic species, only *Zannichellia palustris* and *Potamogeton pectinatus* survive in both bodies of water.

TABLE 6

Summary of the geographical distributions of the submersed vascular aquatic plants that have disappeared from both Put-in-Bay harbor and Lake East Okoboji

Species	Geographical Distribution
Megalodonta beckii	northern
Najas flexilis	northern
Potamogeton amplifolius	northern
Potamogeton friesii	northern
Potamogeton gramineus	northern
Potamogeton natans	northern
Potamogeton praelongus	northern
Potamogeton zosteriformis	northern
Potamogeton nodosus	southern
Potamogeton pusillus	widespread
Elodea canadensis	widespread

University Bay in Lake Mendota, Wisconsin

Changes in the submersed vascular aquatic flowering-plant flora of University Bay in Lake Mendota, Dane County, Wisconsin, were studied in 1966, and were reported by Lind and Cottam (1969). At the time of the original survey in 1922 and of a later survey in 1946, University Bay had 15 species of submersed aquatic plants in common with Put-in-Bay harbor. Of these, only three, *Potamogeton amplifolius*, *Potamogeton praelongus*, and *Potamogeton natans*, all of which have northern distributions and apparently narrow ecological tolerances, have already disappeared from University Bay. In 1922, *Potamogeton amplifolius* was the second most abundant species. These same three species had disappeared from Put-in-Bay harbor by 1949.

Other northern species, such as *Najas flexilis*, *Potamogeton zosteriformis*, and *Elodea canadensis*, which have disappeared from Put-in-Bay harbor in the past 20 years, are still present in University Bay, though the data on the abundance of the plants in 1966 compared with that for 1922 (Lind and Cottam, 1969) suggest that these three species have decreased in numbers. In University Bay, the three most abundant species today are the common, widespread *Myriophyllum exalbescens*, *Vallisneria americana*, and *Ceratophyllum demersum*, the same species that are common in Put-in-Bay harbor. Since 1922 in University Bay, *Myriophyllum exalbescens* and *Ceratophyllum demersum* have increased considerably, with the former becoming the most abundant of all species present. *Vallisneria americana*, which was the most abundant species in 1922, is now second. The loss, decrease, and increase (or continued abundance) of certain species which are common to both University Bay and Put-in-Bay harbor suggest that similar ecological conditions are present in both bodies of water, but that changes in these conditions are apparently not as drastic to this point in time in University Bay of

Lake Mendota as they are in Put-in-Bay harbor in Lake Erie. The trend that is developing in University Bay appears to be the same as that which has already occurred in Put-in-Bay harbor and to a greater extent in Lake East Okoboji, and suggests that, in the future, University Bay may lose additional numbers of its submersed species.

SUMMARY

Man is continually altering and changing the landscape and his environment. The associated flora is also changing. With respect to the vascular aquatic flowering-plant flora of Put-in-Bay harbor, Ohio, and Lake East Okoboji, Iowa, these changes have been drastic—to the extent that 50–60% of the species have disappeared—but these changes are apparently less severe to this point in time in University Bay of Lake Mendota, Wisconsin. Species of clear, cool, well-oxygenated waters whose distributions are primarily northern and whose ecological tolerances are apparently narrow have mostly disappeared, whereas species of turbid, warm, poorly oxygenated waters whose distributions are primarily widespread and whose ecological tolerances are apparently wide have generally survived. Additional comparative studies are now needed in other lakes for which surveys made half a century or more ago are available to determine if similar changes and trends have or are occurring there. Such changes as are reported here should be taken as warnings to man if he intends to maintain high biological diversity in the aquatic flora of lakes and bays.

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REFERENCES

Beeton, Alfred M. 1961. Environmental changes in Lake Erie. Trans. Am. Fish. Soc. 90: 153–159.

——— 1970. Changes in the Environment and Biota of the Great Lakes, p. 150–187. *In* Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, Washington, D.C. 661 pp.

Britt, N. Wilson, Edwin J. Skoch, and **Kenneth R. Smith.** 1967. Record low dissolved oxygen in the island area of Lake Erie. Ohio J. Sci. 68: 175–179.

Carr, John F. 1962. Dissolved oxygen in Lake Erie, past and present. Great Lakes Res. Div., Inst. Sci. & Tech., Univ. Mich. Publ. No. 9. 1–14.

Chandler, David C. 1947. Limnological studies of western Lake Erie. II. Light penetration and its relation to turbidity. Ecology 23: 41–52.

Core, Earl L. 1941. *Butomus umbellatus* in America. Ohio J. Sci. 41: 79–85.

——— 1948. The Flora of the Erie Islands. An Annotated List of Vascular Plants. The Ohio State Univ., The Franz Theodore Stone Lab. Contrib. No. 9. 106 pp.

——— 1949. The plants of western Lake Erie, after fifty years. Unpublished Manuscript (available in the Botany and Zoology Library, The Ohio State Univ., Columbus). 28 pp.

Davis, Charles C. 1969. Plants in Lakes Erie and Ontario, and changes of their numbers and kinds. *In* Proceedings of the Conference on Changes in the Biota of Lakes Erie and Ontario. April 16–17, 1968. Bull. Buffalo Soc. Nat. Sci. 25(1): 18–44.

Dennis, Clyde Avery. 1928. Aquatic Gastropods of the Bass Island Region of Lake Erie, The Ohio State Univ., The Franz Theodore Stone Lab. Contrib. No. 8. 34 pp.

Gaiser, L. O. 1949. Further distribution of *Butomus umbellatus* in the Great Lakes region. Rhodora 51: 387–390.

Hudgins, Bert. 1943. The South Bass Island community (Put-in-Bay). Economic Geography 19: 16–36.

Kennedy, Clarence H. 1923. The ecological relationships of the dragonflies of the Bass Islands of Lake Erie. Ecology 3: 325–336.

Krecker, Frederick H. 1924. Conditions under which *Goniobasis livescens* occurs in the island region of Lake Erie. Ohio J. Sci. 24: 299–310.

——— 1939. A comparative study of the animal population of submerged aquatic plants. Ecology 20: 553–562.

Langlois, T. H. 1944. Fish and farms suffer when the Maumee runs brown. Ohio Conserv. Bull. 8(10): 4–5.

——— 1954. The Western End of Lake Erie and its Ecology. Edwards Brothers, Inc., Ann Arbor. 479 pp. Particularly pages 97–104.

——— 1965. The waves of Lake Erie at South Bass Island. Ohio J. Sci. 65: 335–342.

Langlois, Thomas Huxley, and **Marina Holmes Langlois.** 1948. South Bass Island and Islanders. The Ohio State Univ., The Franz Theodore Stone Lab. Contrib. No. 10. 139 pp.

Lanjouw, J., and **F. A. Stafleu.** 1964. Index Herbariorum. Part 1. The herbaria of the world. 5th ed. Regnum Vegetabile 31: 1–251.

Lind, Christopher T., and **Grant Cottam.** 1969. The submerged aquatics of University Bay: A study in eutrophication. Am. Midl. Nat. 81: 353–369.

Meyer, Bernard S., and **Albert C. Heritage.** 1941. Effect of turbidity and depth of immersion on apparent photosynthesis in *Ceratophyllum demersum*. Ecology 22: 17–22.

Meyer, Bernard S., Frank H. Bell, Lawrence C. Thompson, and **Edythe I. Clay.** 1943. Effect of depth of immersion on apparent photosynthesis in submersed vascular aquatics. Ecology 24: 393–399.

Moseley, E. L. 1899. Sandusky Flora. A catalogue of the flowering plants and ferns growing without cultivation, in Erie County, Ohio, and the peninsula and islands of Ottawa County. Ohio State Acad. Sci. Special Papers No. 1. 167 pp.

Pieters, A. J. 1901. The plants of western Lake Erie, with observations on their distribution. Bull. U. S. Fish Comm. 21: 57–79.

Shawver, Nellie Maude. 1931. The plankton algae of Put-in-Bay harbor, M. S. Thesis, The Ohio State Univ., Columbus. 28 pp.

Stansbery, David H. 1961. The naiades (Mollusca, Pelecypoda, Unionacea) of Fishery Bay, South Bass Island, Lake Erie. Part I. Introduction, History, Faunal Origins, and Physiography. Sterkiana 5: 1–37.

Stehle, Mabel E. 1923. Surface plankton protozoa from Lake Erie in the Put-in-Bay region. Ohio J. Sci. 23: 41–54.

Stuckey, Ronald L. 1968a. Distributional history of *Butomus umbellatus* (flowering-rush) in the western Lake Erie and Lake St. Clair region. Mich. Bot. 7: 134–142.

——— 1968b. Aquatic flowering plants new to the Erie Islands. Ohio J. Sci. 68: 180–187.

Thorndale, Theresa. 1898. Island Jottings. Sandusky Weekly Register. 30 March: 11.

Tiffany, Lewis Hanford. 1934. The Plankton Algae of the West End of Lake Erie. The Ohio State Univ., The Franz Theodore Stone Lab. Contrib. No. 6. 112 pp.

——— 1937. The filamentous algae of the west end of Lake Erie. Am. Midl. Nat. 18: 911–951.

U. S. Lake Survey. 1966. Recreational Craft Series Chart No. 360 South Shore of Lake Erie. From Port Clinton to Sandusky, Ohio, including Sandusky Bay. U. S. Army Corps of Engineers. 35 p.

Verduin, Jacob. 1964. Changes in western Lake Erie during the period 1948–1962. Verh. Internat. Verein. Limnol. 15: 639–644.

——— 1969. Man's influence on Lake Erie. Ohio J. Sci. 69: 65–70.

Volker, Roger, and **S. Galen Smith.** 1965. Changes in the aquatic vascular flora of Lake East Okoboji in historic times. Proc. Iowa Acad. Sci. 72: 65–72.